NASA WORLDWIDE TRACKING SYSTEMS

By

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A Synopsis

The paper is divided into four parts. The first part deals with the factors which influenced the type, size, and the amount of equipment selected for the different NASA tracking and data-acquisition networks; the second part describes the NASA Deep Space Instrumentation Facility; the third part the Minitrack Network, which was developed for unmanned-earth-satellite programs; and the fourth part the Mercury Man-in-space tracking and ground-instrumentation system.

Part I. General

Figure 1 presents the more important factors affecting the selection of the ground equipment for tracking and data-acquisition networks. Figures 2, 3, and 4 deal with the number and arrangement of the stations that may be

SOME IMPORTANT FACTORS AFFECTING
NETWORK EQUIPMENT

MISSION

ALTITUDE OR DISTANCE

ONBOARD EQUIPMENT

MANNED

RECOVERY

Fig. 1

required. Figure 2 shows how a minimum of four stations may be located to give complete sky coverage. The coverage, however, is not complete until an altitude of about one earth's diameter is exceeded. For complete coverage for satellites at lower altitudes, the number of stations must be increased. If once-an-orbit contact is sufficient for low-altitude satellites, a line of stations forming a "fence" can be employed. Figure 4 illustrates how an equatorial fence is especially suitable for polar orbits and a north-south fence for low-angle orbits. Figure 5 shows the tremendous variation of transmitted-power or antenna-effectiveness requirements with distance and band width. Fortunately, although distance increases the power requirements, it reduces the number of stations needed. The remaining figures in the first part

COMPLETE SKY COVERAGE
WITH A 4-STATION NETWORK
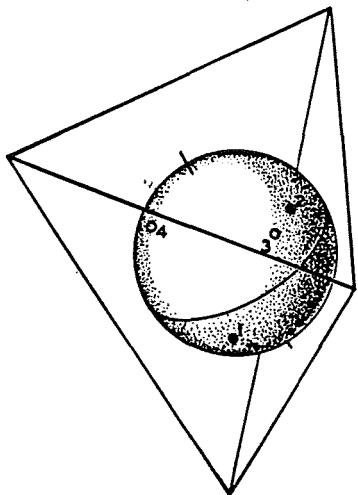
Fig. 2

POLAR, EQUATORIAL AND INTERMEDIATE ORBITS

Fig. 3

(277)
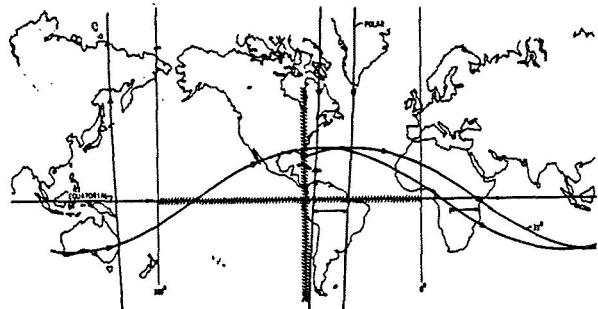
Fig. 4

RADIO POWER REQUIRED FOR SATELLITES & PROBES
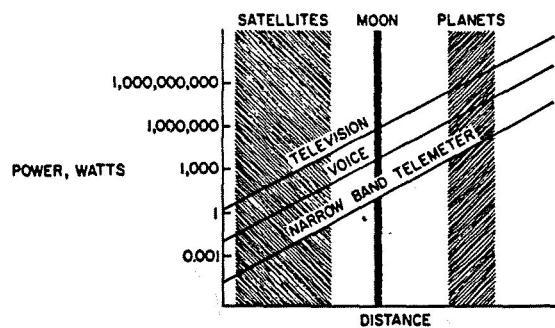
Fig. 5

(Figs. 6, 7, and 8) illustrate the elements normally used to define an orbit and the measurements that have been suggested to determine them.

Part II. Deep Space Instrumentation Facility

The Deep Space Instrumentation Facility was developed by the Jet Propulsion Laboratory of the California Institute of Technology and operated by JPL under contract to the NASA. In the design advantage was taken of the fact that current deep-space probes are launched in the plane of the ecliptic and the facility consists of three stations rather than the minimum of four needed for complete sky coverage. In addition to three permanent stations located approximately 100° to 120° of longitude apart, the facility includes a mobile station which is normally located under the point of in-

(278)
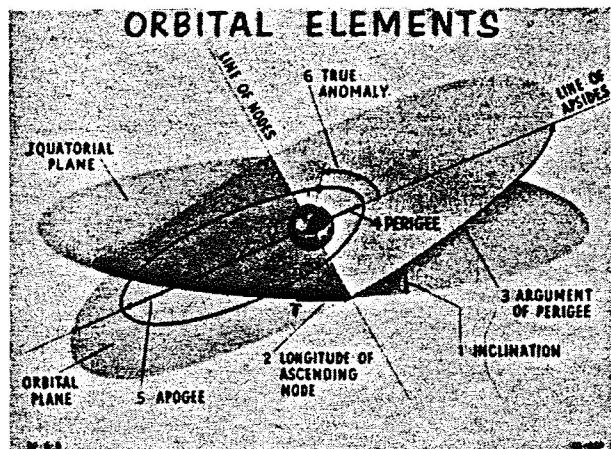
Fig. 6

MEASUREMENTS FOR ORBIT DETERMINATIONS

| METHOD	TIME	ALTITUDE	LONGITUDE	RANGE	VELOCITY	MINIMUM OBS. REQ'D	TYPICAL SYSTEM
MERIDIAN CROSSING	✔	✔	✔			3	MOONWATCH, MINITRACK
ANGULAR BEARINGS	✔	✔	✔			3	BN CAMERA, TRACKING ANT.
VELOCITY ONLY	✔				✔	6	DOPPLER
RANGE ONLY	✔			✔		6	PROPOSED
RANGE & ANGLE	✔	✔	✔	✔		2	TRACKING RADAR

Fig. 7

(279)
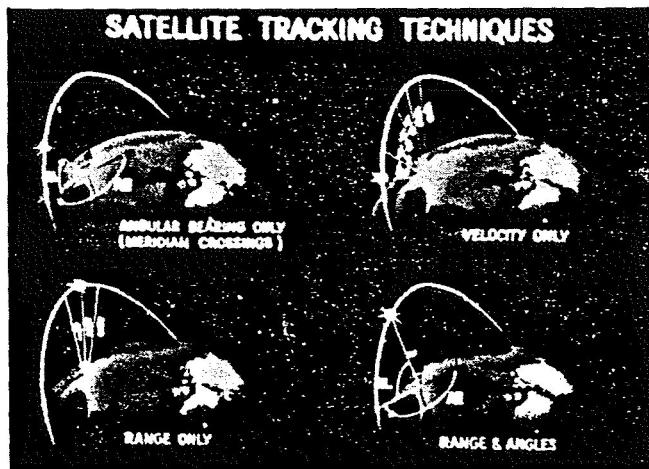
Fig. 8

Fig. 9

sertion and is used for monitoring this phase of an operation. The locations of the stations and the sky coverage as a function of altitude are shown in Figures 9 and 10. Figure 11 lists the basic equipment at each station and Fig. 12 the capabilities of this equipment. Figure 13 illustrates the geographical arrangement of the Goldstone station, the only station having both receiving and transmitting antennas. Figures 14 and 15 show the antennas and Fig. 16 the mobile station. Figure 17 is a functional diagram of the Goldstone station showing how the transmitting antenna can be slaved to the receiving antenna.

(280)

STATION COVERAGE

Fig. 10

DEEP SPACE INSTRUMENTATION
FACILITY (DSIF)

	GOLDSTONE USA	WOOMERA AUSTRALIA	JOHANNESBURG SA	MOBILE
LONGITUDE LATITUDE	116.848°W 35.389°N	136.886°E 31.382°S	27675°E 25891	LOCATED BELOW INJECTION POINT
BASIC EQUIPMENT	TWO 85 FT DIG ANTENNAS (ONE FOR TRACKING AND TELEMETRY RECEP)(ONE WITH 10 KW POWER FOR DOPPLER AND COM— MAND TRANS- MISSION)	ONE 85 FT DIG ANTENNA (FOR TRACKING AND TELEMETRY RECEP)	ONE 85 FT DIG ANTENNA (FOR TRACKING AND TELEMETRY RECEP)	ONE 10 FT DIG ANTENNA (FOR ALL FUNCTIONS UP TO 10,000 MILES)

Fig. 11

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DSIF CAPABILITIES

ANGULAR TRACKING ERRORS
    85 FT ANTENNAS — .01 TO .05 DEG RMS
    10 FT ANTENNA — .1 DEG RMS

RADIAL VELOSITY ERRORS
    GOLDSTONE AND MOBILE STATIONS — .17 M/SEC
    WOOMERA AND JOHANNESBURG STATIONS — 10 M/SEC

TIME SYNCHRONIZATION TO WWV
    GOLDSTONE STATION — 1 MS
    OTHERS — 10 MS

RECEPTION FROM SPACECRAFT
   ≈ 20,000,000 STATUTE MILES

Fig. 12

Fig. 13

Fig. 14

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Fig. 15

Fig. 16

Fig. 17

(283)
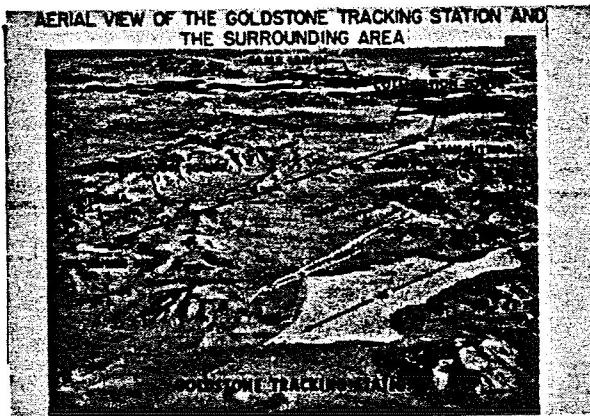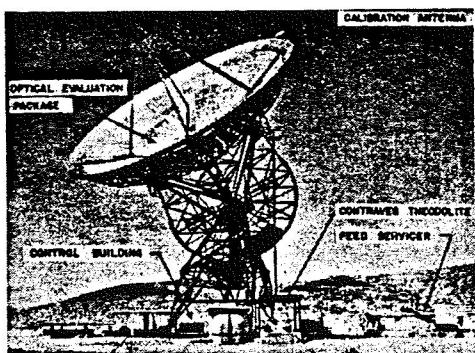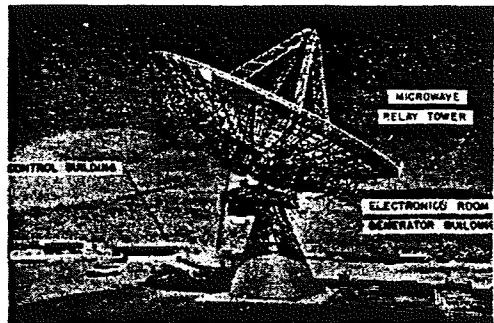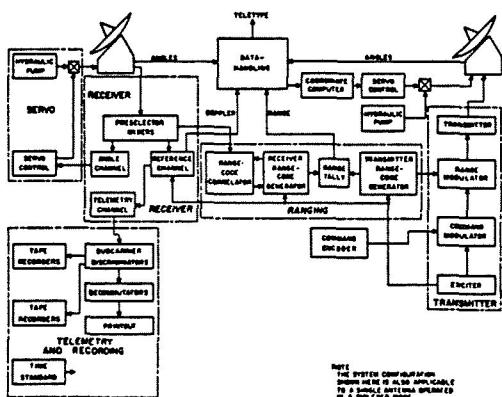
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Renzetta, N. A., Fearey, J. P., Hall, J. R., and Ostermeier, B. J.: Radio Tracking Techniques and Performance of the United States Deep Space Instrumentation Facility. Jet Propulsion Laboratory, Tech. Rept. No. 32-87.

Hall, J. R.: System Capabilities and Development Schedule of the Deep Space Instumentation Facility 1961-1966. Jet Propulsion Laboratory, Tech. Memo. No. 33-27.

Part III. Minitrack Network

The Minitrack Network was developed by the Naval Research Laboratory for the Vanguard project and transferred to the NASA with the project. It is intended for once-an-orbit satellite contact. The locations of the stations forming a north and south fence across North and South America are shown in Fig. 18. Figure 19 shows a typical station layout and Fig. 20 one of the antennas. The network employs the refraction principle for tracking. Figure 21 illustrates the phase angle relationship between a pair of antennas, and Fig. 22 gives the layout of the antennas which permits simultaneous measurements for several pairs of antennas to eliminate the ambiguities that exist when the phase angle exceeds 360°. The output of a station is in terms of the direction cosines of the line of sight to the satellite (Fig. 23). The electronics of the measurement system is illustrated in Fig. 24. Figure 25 is a sample data record. After the ambiguities are resolved, the direction cosines for 1-second intervals are transmitted in the format shown in Fig. 26 to a computing center located at the NASA Goddard Space Flight Center. Figure 27 lists the system constants and the precision of data obtained.


Fig. 18

Fig. 19

Fig. 20

Fig. 21

(285)

Fig. 22

ZENITH

TO
SATELLITE

N

A₄

A₁   E

A₂

A₃

Fig. 23

Fig. 24

(286)

Fig. 25
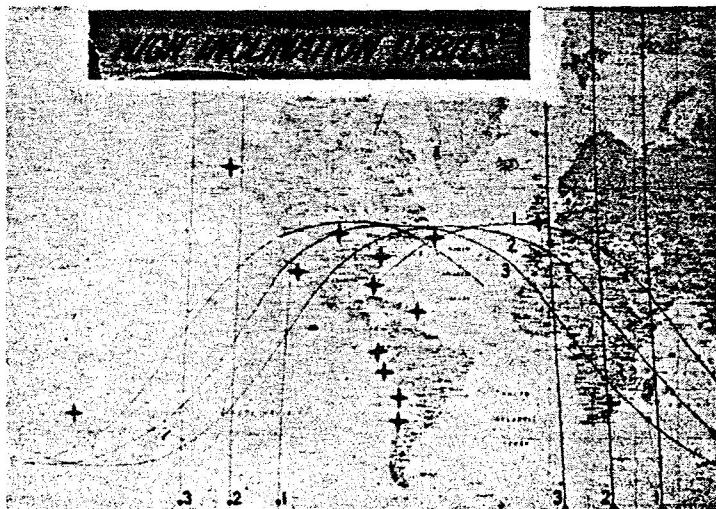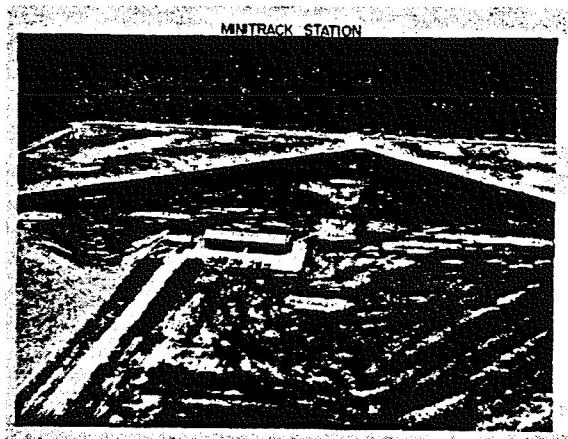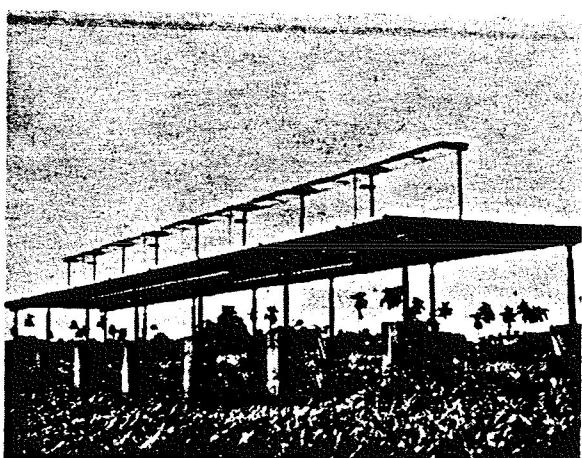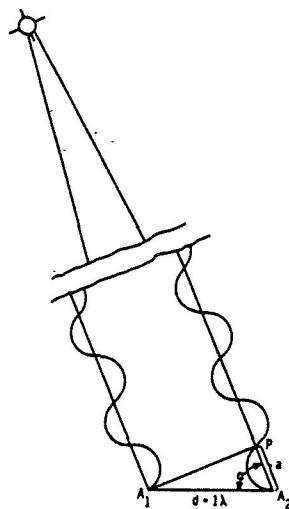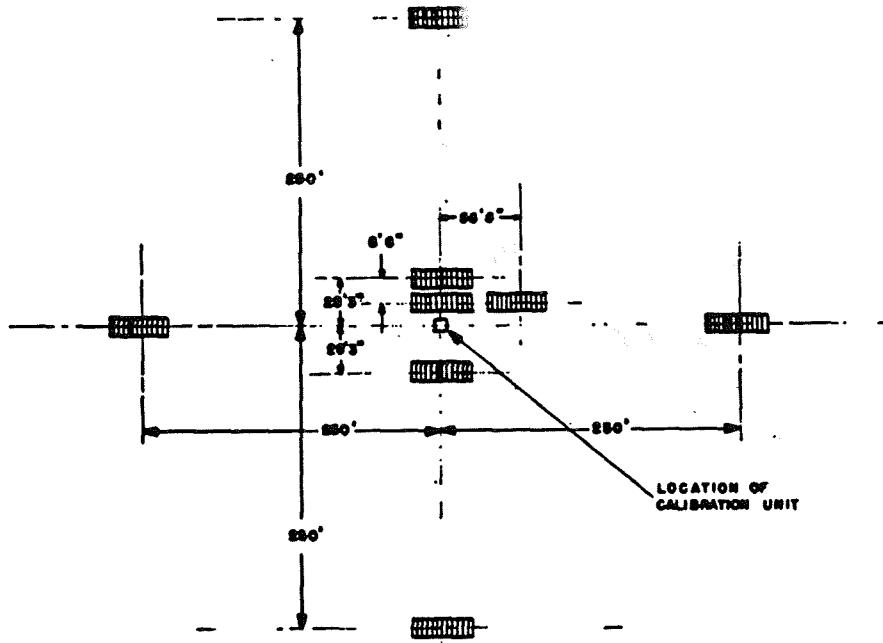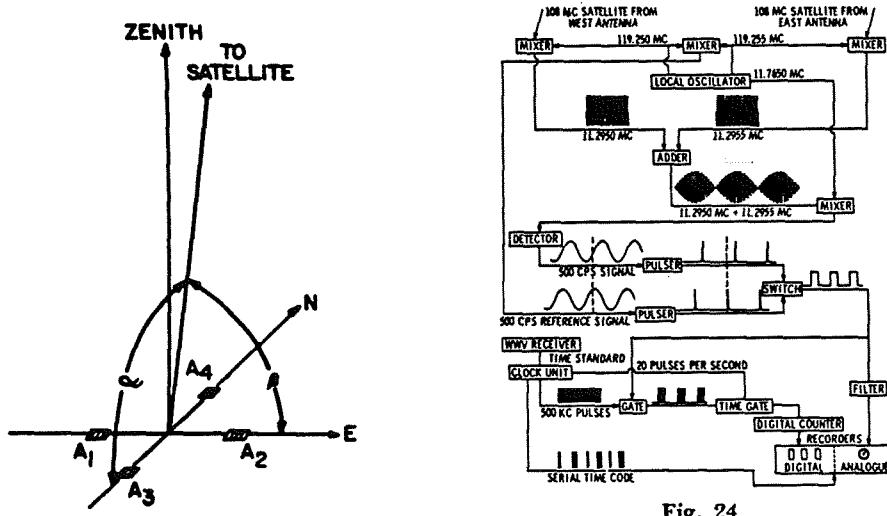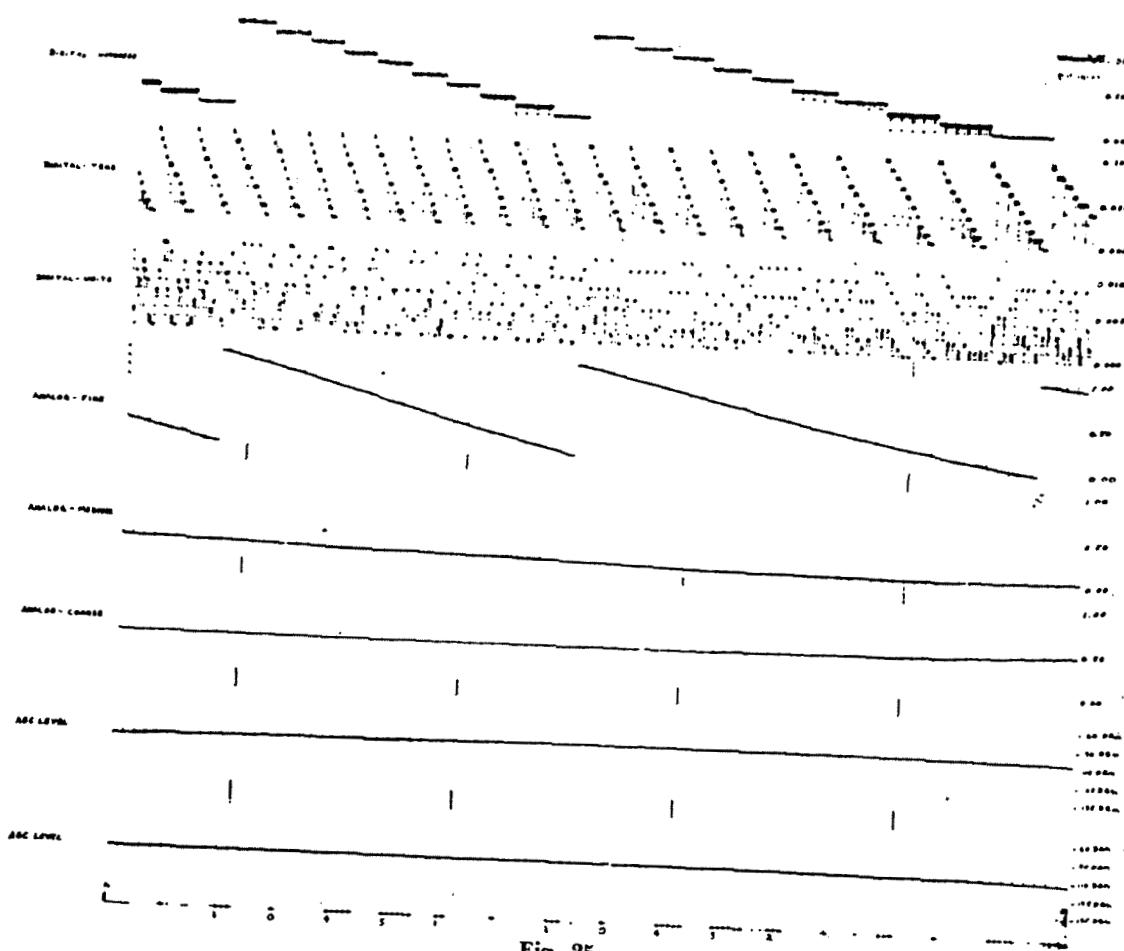
SAMPLE MINITRACK MESSAGE

K̸	a b c	STATION
BPOINT	570309	DATE (a) Year (b) Month (c) Day
	d e f	
d e f	d e f	TIME OF FIRST READING (d) Hour (e) Min (f) Sec
224624	224635	TIME OF LAST READING same
	g h	
g h	g h	PRE-PASSAGE CALIBRATION (g) East-West
180218	180218	POST-PASSAGE CALIBRATION (h) North-South
j k		SIGNAL LEVEL (j) East-West (k) North-South
110115	999005	QUALITY OF SIGNAL
		SATELLITE SERIAL NUMBER
K a	K a	EAST-WEST MINITRACK READINGS
043555	038090	NORTH-SOUTH MINITRACK READINGS
		(K) Whole cycle reading
		(a) Fractional cycle reading - in thousandths

044769	037591

STATION ABBREVIATIONS   SATELLITE NUMBERS

046003	037162

Antigua (prime)	PANTIG	1957 ALPHA	001
Antigua (east)	EANTIG	1957 BETA	002
Antigua (west)	WANTIG	1958 ALPHA	003
Antofagasta	AGASTA	EXPLORER II	004
Blossom Point	BPOINT	1958 BETA	005

047270	036790

Fort Stewart	FTSTEW	1958 GAMMA	006
Havana	HAVANA	TV-5	007
Lima	LIMAPU	1958 DELTA	008
Quito	QUITOE	SLV-1	009

048566	036480

San Diego	NELCAL
Santiago	SNTAGO
Grand Turk (up range)	UGRAND
Grand Turk (Down range)	DGRAND

049878	036236

Woomera	OOMERA
Johannesburg	JOBURG

051207	036045

052541	035900	NOTE: Slant symbols indicate that part
		or all of a data point was not
		readable.
053879	035808	No redundancy checks are given as
		it is intended that the complete
		message will be transmitted three
		or more times. This message is
055210	035752	expanded for clarity; normally the
		two column message would be typed
		on consecutive lines

///////	X//////
057857	035743

d e f	d e f	TIME OF FIRST READING (Same as above)
224624	224635	TIME OF LAST READING
		COMPUTER END-OF-MESSAGE SYMBOL

Fig. 26

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MINITRACK SYSTEM CONSTANTS

Frequency	108 Mc
Baseline length (fine)	54.9 /
Antenna beam (fan)	100° -10° at 6db pts.
Max. Resolution	4 sec of Arc
Max. Accuracy	20 sec of Arc
Pre-detection Bandwidth	10 Kc
Post-detection Bandwidth	8 cps
Signal for 1° rms Phase Noise	122 Dbm
Calibration Accuracy	Approx. 2 sec of Arc
Timing Accuracy	± 1 to ± 2 Milliseconds (dependant upon distance from WWV)

Fig. 27

Bibliography

Hagen, J. P.: Satellite Tracking.
Carpenter, H. E., Jr., and Madden, J. J.: Minitrack.
Mengel, J. T., and Herget, P.: Tracking Satellites by Radio. Scientific American, Jan. 1958.

Part IV. Mercury Tracking and Ground Instrumentation System

The Mercury Tracking and Ground Instrumentation System was constructed to track the Mercury capsule during a three-orbit mission and to monitor the condition of the astronaut and his life-support equipment. In case the astronaut is incapacitated during a mission, the system is able to command the return of the capsule from orbit. Continuous coverage would have been desirable but was shown by study to be impracticable from the expense standpoint. As evolved, the network consists of 18 ground stations tied together by a ground communication system which operates, for the most part, in "real" time. Figure 28 shows the locations of the stations. All stations but one are equipped with telemeter receivers and equipment for voice communication with the astronaut. Ten of the stations are equipped with radars for tracking. Five are equipped with command transmitters by means of which a ground observer can order the capsule to descend from orbit in an emergency or up-date the time for the programed reentry. The types of equipment at the different stations are illustrated by Fig. 29. Figures 30 and 31 show the antennas of the Verlort and FPS-16 tracking radars. The layout of the central control station at Cape Canaveral is given in Fig. 32. Figure 33 is a photograph of the command area showing the world map and the consoles at which the various specialists receive their information.

(289)

Fig. 28

Fig. 29

(290)

Fig. 30

Fig. 31

(291)
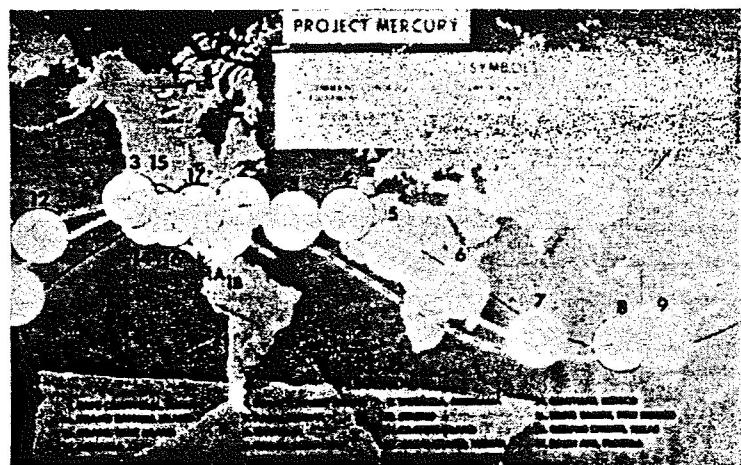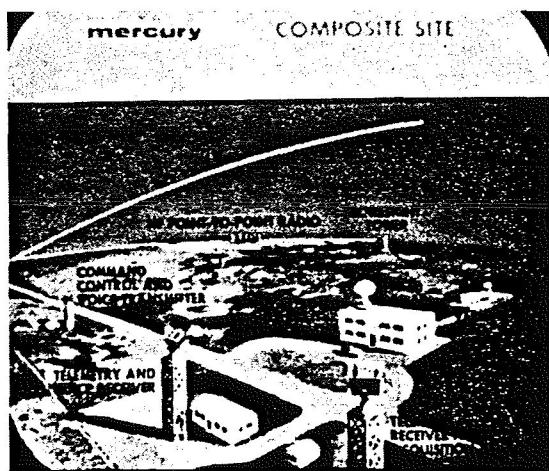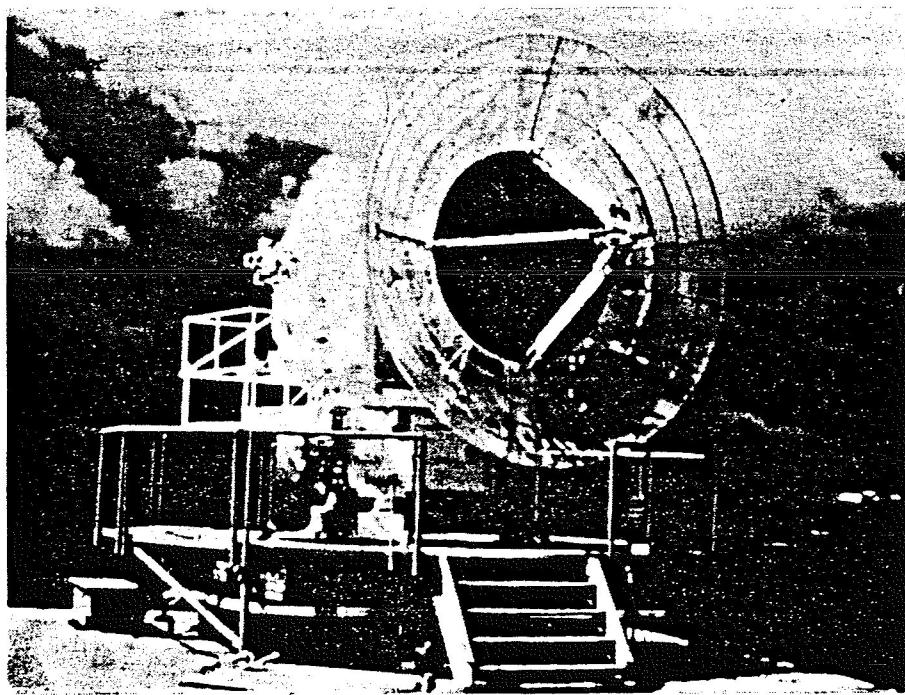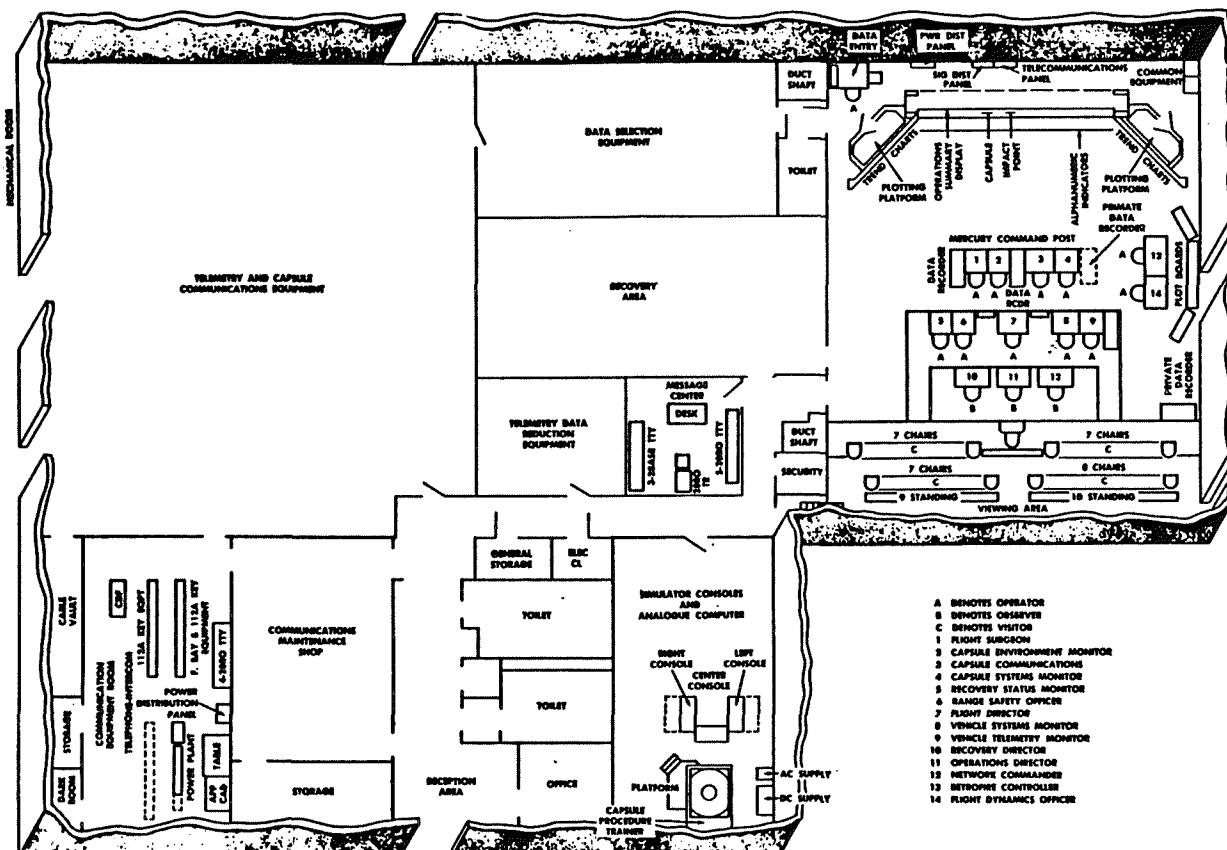
Fig. 32   FLOOR PLAN, TEL-3 BUILDING—CAPE CANAVERAL
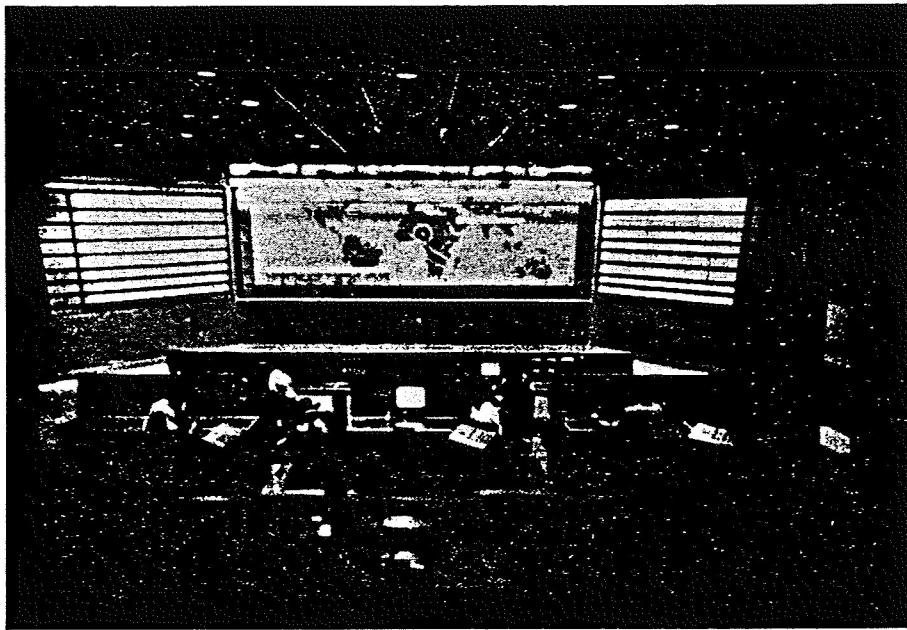
Fig. 33

Figures 34 through 39 deal with the ground communication system essential to the operation of the Mercury network. With regard to ground communications, because of the possibility of solar interference on radio transmission complete reliance is placed on the communication system to pass information back to control central in "real" time only when telephone lines or cables can be used. Whenever radio links are required, it is planned to have teams of specialists at the stations capable of making local decisions if contact with the control center is lost. The telephone, cable, and radio links are shown in Fig. 34. All lines pass through the Goddard Space Flight Center at Greenbelt, Maryland, on the way to the control center at Cape Canaveral. Figure 35 shows the arrangement around the antennas at the Kano station which not only originates traffic but acts as a relay station for traffic from Zanzibar and the Indian Ocean ship. The ships offered special problems because the transmitting and receiving antennas could not be separated to the extent possible at the land stations. The ship antenna arrangement is shown in Fig. 36. Primary reliance is placed on teletype circuits for transmission or radar information. Voice circuits are generally confined to the United States. Broad-band data circuits are used for transmission of critical launch data between Cape Canaveral and the computers at Goddard (Fig. 37). Figure 38 shows the switching arrangements for teletype data in Hawaii. A functional diagram of communications during the critical launch period is presented in Fig. 39.

(293)

Fig. 34

Fig. 35

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HF ANTENNA SYSTEM
ON
ATLANTIC AND INDIAN OCEAN SHIPS
PROJECT MERCURY
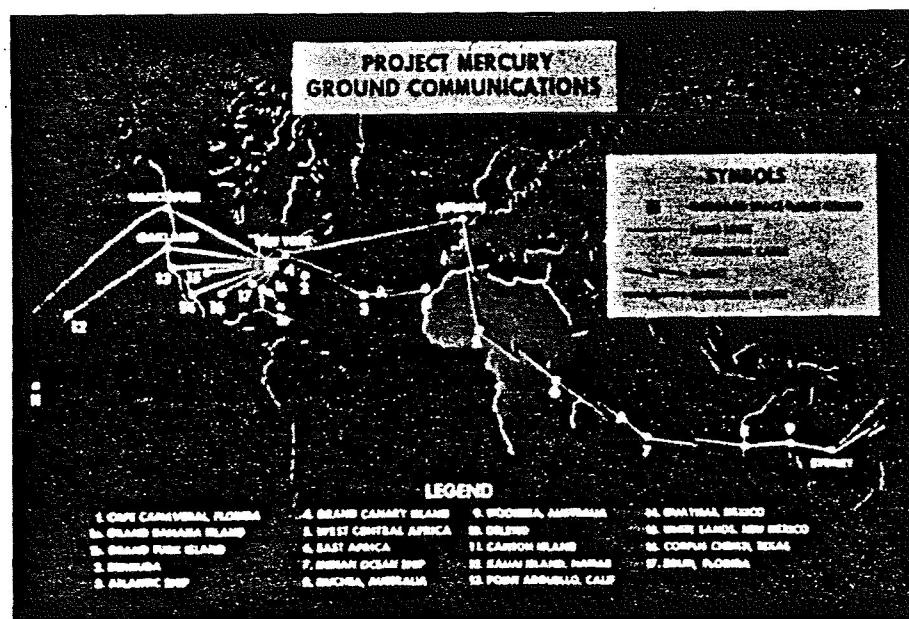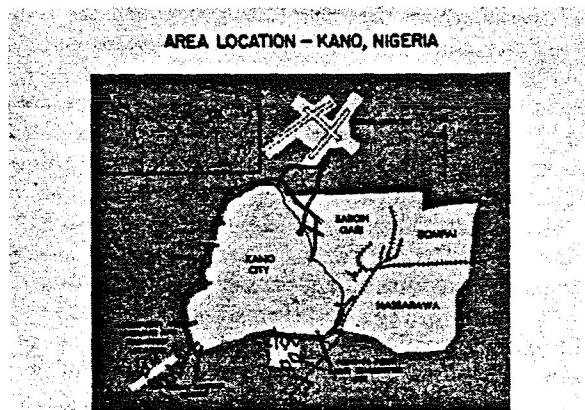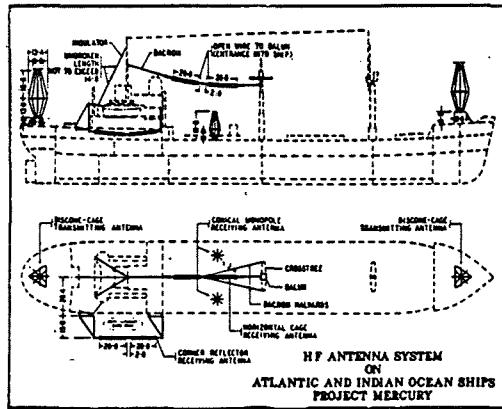
Fig. 36


Fig. 37

Fig. 38

Fig. 39

(296)
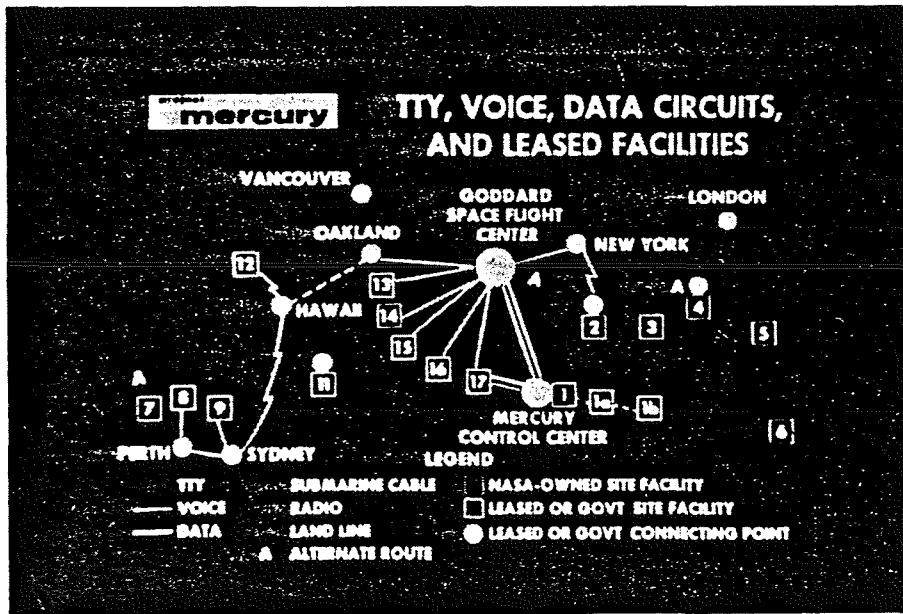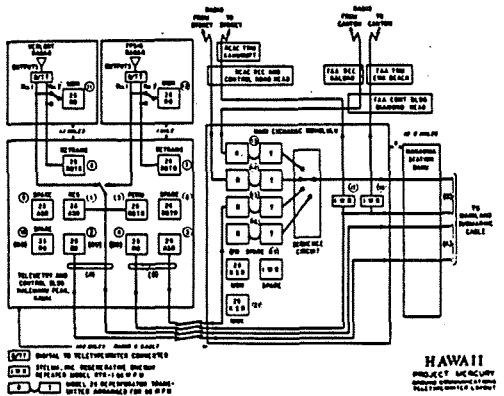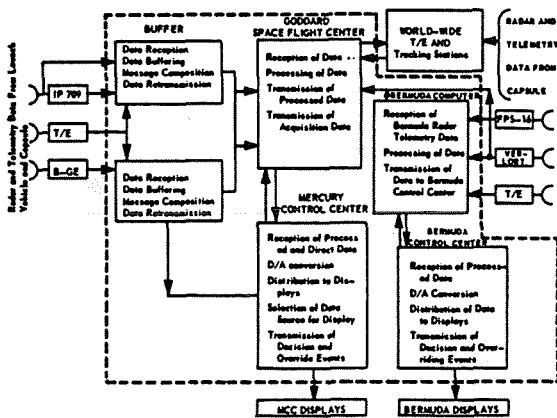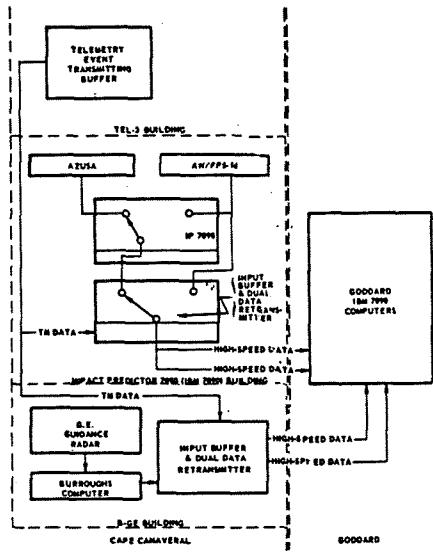
Fig. 40

In order to provide information for launch-period decisions, an elaborate computing system is used for evaluation of launch guidance and tracking data. Two computers are located at Goddard and a third in Bermuda. The Bermuda computer is a hedge against a failure of communications. The remaining figures are related to this computing system. Figure 40 shows the data sources available for launch computations at Canaveral and the switching arrangement that facilitates the choice and transmission of the best data to the Goddard computing center. The role of the Goddard computing center is shown in Fig. 41 while Fig. 42 is illustrative of the layout of the computers at Goddard. Dual computing equipment is employed to increase reliability. Bermuda is a secondary command station. The relationship between the Cape Canaveral and Bermuda control centers, insofar as the launch decision is concerned, is illustrated in Fig. 43. The final figure, Fig. 44, shows the type of information that is printed out by the computers. From this printed information, the computer personnel can discern whether or not the machines are functioning properly.

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ROLE OF COMPUTERS

	INPUTS		COMPUTATION	OUTPUTS
L A U N C H	IP 709 B-GE FPS-16 T/M	} 1000 BITS SEC.	TRAJECTORY PARAMETRS. GO-NO GO CALCULATIONS, IMPACT POINTS, ACQUISITIONS.	EVERY 1/2 SEC. TO MERCURY CONTROL, TO GODDARD, TO BERMUDA.
A B O R T	IP 709 FPS-16 T/M	} 1000 BITS SEC.	TRAJECTORY PARAMETERS, REFINED IMPACT,	EVERY 1 SEC. TO CONTROL TO GODDARD
	MANUAL INPUT FPS-16 VERLORT	} 30 BITS SEC.	PRESENT POSITION.	
O R B I T	MANUAL INPUT, FPS-16, VERLORT	} 30 BITS SEC.	EDIT, INTEGRA-TION, DIFFERENTIAL CORRECTION, ORBIT PARA-METERS, TIME TO RETRO-FIRE, ACQUISITION	EVERY 10 SEC. TO MERCURY CONTROL, TO GODDARD, TO ALL SITES.
R E-E N T R Y	FPS-16 VERLORT MANUAL INPUT	} 30 BITS SEC.	EDIT, INTEGRA-TION, (DRAG) NUMERICAL DIFFERENTIAL CORRECT, REFINED IMPACT POINT, ACQUISITION, LANDING TIME	EVERY 5 SEC. TO MERCURY CONTROL, TO GODDARD, TO ALL SITES.

Fig. 41

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Fig. 42

Fig. 43

(299)
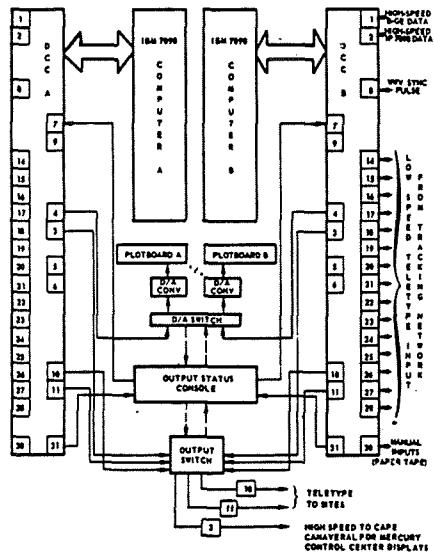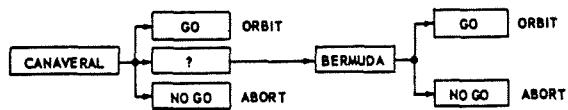
```
00.00.00 NORMAL OPERATION BEGUN
00.00.04 THE WWV TIME ENTERED IS (GMT) 00 HRS 00 MINS 00 SECS
00.00.18 STATION CHARACTERISTICS TAPE HAS BEEN READ SUCCESSFULLY
00.00.30 THE TIME OF LIFT-OFF IS (GMT) 00 HRS 00 MINS 29 SECS
00.02.05 HS OUTPUT TRANS. RATE TO CAPE EXPECTED, 240, ACTUAL 211
00.03.06 TOWER SEPARATION SIGNAL HAS BEEN RECEIVED 1247
00.03.20 BERMUDA FPS/16 ACQUISITION DATA SENT
00.03.48 BERMUDA FPS/16 ACQUISITION DATA SENT
00.04.01 HS OUTPUT TRANS. RATE TO CAPE EXPECTED, 240, ACTUAL 240
00.04.18 BERMUDA FPS/16 ACQUISITION DATA SENT
00.04.47 BERMUDA FPS/16 ACQUISITION DATA SENT
00.05.20 SECO SIGNAL HAS BEEN RECEIVED 2344
00.05.21 CAPSULE SEPARATION HAS BEEN RECEIVED 2332
00.05.25 THREE POSIGRADE ROCKETS WERE FIRED
00.05.26 NINE POINTS WERE USED TO CALCULATE FINAL GO-NO GO
00.05.28 GO IS RECOMMENDED
00.05.28 THE TIME OF RETROFIRE IS (GMT) 00 HRS 05 MINS 48 SECS
00.05.29 VELOCITY USED IN FINAL GO-NO GO IS (FEET PER SEC) 25628
00.05.30 GAMMA USED +8.2530713, -03 FINAL GO-NO GO (IN DEGREES)
00.05.35 BERMUDA VERLORT HAS BEGUN TRANSMISSION
00.05.50 LAUNCH  RX = 57344462152S  RY = 600705771112  RZ = 200410256770
00.05.51 LAUNCH  VX = 200757032365  VY = 175546161651  VZ = 176570565117
00.05.51 TIME (LO) 21146764474 FL  PT
00.05.56 FL  PT/OCT  RX = 173642641200  RY = 60070343261l  RZ = 200414245722
00.05.57 FL  PT/OCT  VX = 200756760443  VY = 175774623460  VZ = 176514343627
00.06.02 ANCHOR TIME FOR ABOVE  R.V .VALUES EQU 00 HRS 06 MINS 00 SECS
00.06.06 ORBIT PHASE HAS BEEN ENTERED
00.06.09 EDIT, DIFFERENTIAL CORRECTION PROGRAMS REQUESTED
00.06.16 THE NUMBER OF RECORDS WRITTEN ON THE RESTART TAPE IS 1
00.06.20 NUMERICAL INTEGRATION HAS BEEN SUCCESSFULLY COMPLETED
00.06.21 APOGEE N.M. +1.0677706, +02, +0.0000000, -40 PERIGEE N.M.
00.06.23 HS OUTPUT TRANS. RATE TO CAPE EXPECTED, 20, ACTUAL 2
00.06.28 A NEW REENTRY TABLE HAS BEEN GENERATED
00.06.32 BERMUDA FPS/16 HAS BEGUN TRANSMISSION
00.06.34 M.A.S. TELEMETRY ACQUISITION DATA SENT
00.06.38 CANARIES VERLORT ACQUISITION DATA SENT
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Fig. 44

Bibliography

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Schindell, L. M.: Global Communications for Project Mercury Using Facilities of Common Carriers.